TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 382

EXPERIMENTS WITH ROTATING CYLINDERS IN COMBINATION WITH AIRFOILS

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From "Zeitschrift für Flugtechnik und Motorluftschiffahrt"
August 28, 1926

Washington
October, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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EXPERIMENTS WITH ROTATING CYLINDERS IN COMBINATION WITH AIRFOILS.*

By Kurt Frey.

The question continually arises as to whether rotating cylinders can be advantageously used in combination with airfoils in airplane construction. The American experiments are known ("Tests of Rotating Cylinders" by Elliott G. Reid, National Advisory Committee for Aeronautics, Technical Note No. 209), as also the Dutch experiments by Dr. E. B. Wolff (N.A.C.A. Technical Memorandum No. 307). Dr. Wolff continued his experiments and published an account of them in "De Ingenieur," 1926, No. 10, pp. 181-190. No one has yet succeeded, however, in the endeavor to find a utilizable polar for landing and for horizontal flight. As a further contribution to the solution of the problem, I am publishing a portion of the wind tunnel work of the Hannover Technical High School, which was done by Engineer Boris and myself, with the friendly support of Professor Pröll and Oesterlen and the Junkers Works, between December, 1924, and February, 1926.

* "Versuche mit rotierenden Zylindern in Verbindung mit Tragflachen," Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 28, 1926, pp. 342-345.

The Göttingen airfoil No. 482 was divided into Parts I and III in such a way that a rotatable cylinder was partially enclosed as Part II, leaving in its rear a uniform narrow gap and in front a somewhat wider tapering gap, with its narrowest cross section on the upper or suction side of the airfoil. Shields IV were fastened to the ends of the airfoil (Fig. 1).

The dimensions of the airfoil were determined by the dimensions of the wind tunnel, which had an inside diameter of 35 cm (13.78 in.) and a maximum wind velocity of 7 m/s (23 ft./sec.). A span (b) of 20 cm (7.87 in.) and a chord (t) of 7 cm (2.756 in.) were chosen. The aspect ratio was therefore $\lambda = t/b = 1/2.9$. The diameter of the cylinder was 1 cm (0.394 in.). The unfavorable aspect ratio was chosen in order to obtain the maximum peripheral speed.

Since no absolute c_a and c_w values could be obtained with the means at our disposal, extensive comparative experiments had to be carried out. The Göttingen airfoil 482 was made with the same dimensions as model II and was used as a comparative model in the following experiments:

a) Finding the polar for model II;

b) Finding the polar for model II with end shields as on model I;

c) Finding the polar for model I with rotor at rest;

d) Finding the polar for model I with rotor in motion;

e) Testing the effect of changing the ratio of peripheral speed to wind velocity $(u : v)$ with α constant;

f) $v = 0$, but with rotor in motion.

Experiments a - c were performed with an available two-component spring balance, a and c-f on a balance built especially for this purpose (Figs. 2-3). In these experiments, a motor which was rotatable about a horizontal and a vertical axis, was located at the center of rotation. The rotary motion was transmitted to the cylinder by an encased steel shaft 5 mm (0.2 in.) thick and 50 cm (32 in.) long. The rotational speed of the cylinder was 10,000 R.P.M., which gave a peripheral speed of 5 m (16.4 ft.) per second. In order to obtain more accurate readings, all the experiments were performed with v = about 6 m (19.7 ft.) per second. Hence $u/v = 0.8 - 0.9$.

As already stated, the experiments were divided into two groups:

α) With an old two-component spring balance;

β) With a new two-component balance.

After calibration of the balance, the experiments a-c were performed and the experimental points in Fig. 4 were connected by compensating curves, whereby not c_a and c_w, but A and W in grams of spring tension were plotted on the coordinate axes.

After determining the sensitivity of the balance, experiments a and c-f were performed, and the experimental points for experiments a, c and d, in Fig. 5, and for experiment e, in Figs. 6-7, were connected by compensating curves. Here also c_a and c_w were not plotted, but the values of A and W in grams, as measured on the scale pans - experiment f, at $\alpha = 0^\circ$, gave a small thrust, only when the tapering gap was narrowed on the suction side.

The conversion into c_a and c_w values for plotting in the diagrams was omitted, as a constant reminder that, with the available means, no calculations with absolute values could be made at first. They are intended only for comparison with the well-known Göttingen polars in absolute values.

α) The experiments under α proved that, in spite of the small dimensions and speeds (therefore in an unfavorable index-value region), the expected characteristics could be obtained, as also the effect of the end shields and, in experiment c, the anticipated dependence on the effect of the divided wing.

β) Fig. 5 shows, for experiments a and c, the same results as under α, thus proving that the new balance was sufficiently accurate. Experiment d, which tested the effect of the rotating cylinder, showed a lift increase of about 86% as compared with the Göttingen experiments on the airfoil. The conspicuously sharp maximum was repeatedly measured, as also the remarkable double bend in the polar curve. The angles of attack were not read simultaneously, because the change for $c_{a\ max.}$ was relatively small, and the execution of the experiment was thus made considerably easier. In order to emphasize the numerical inaccuracy still further, the parabola for the induced drag was also added. Corresponding to the other curves, the parabola was so drawn that every point gives the drag (in grams on the scale pan), which maintains the equilibrium against the induced drag of the Göttingen airfoil.

Two diagrams (Figs. 6-7) were drawn for experiment e, so as to make the result clearer. Fig. 6 shows, for constant α and variable u/v, the relation of the lift coefficients for the rotor in motion and at rest. In like manner, Fig. 7 shows the relation of the drag coefficients. The experiments showed accordingly that the relation of the lift coefficients in the investigated region is almost independent of u/v, while the relation of the drag coefficients is very strongly dependent on u/v.

The next task was to perform comparative experiments with a reliable wind tunnel. This was rendered possible through the courtesy of the Junkers Works in Dessau. In these experiments, with $\lambda = 1/1$, circular end shields which turned with the rotor were used instead of the stationary shields covering the cross section of the airfoil. Experiments were tried under the following conditions:

a) Rotor at rest, gap open;

b) Rotor running, gap open;

c) Rotor running, gap changed;

d) Variation of u/v;

e) Rotor at rest, gap completely closed on both suction and pressure sides of airfoil.

In comparison with a, b showed only a very slight improvement, which grew proportionately less with increasing α. Hardly any effect was produced by c and d. Comparison of e with a was intended to show whether there was still any divided wing effect. It was found that no such effect was apparent.

I thought these quite different results must be explained by the aspect ratio and the changed arrangement of the model and accordingly performed the same experiments in the wind tunnel of the Hannover Technical High School with a geometrically similar model. These gave the same results as the experiments performed in the Junkers Works. It was thus demonstrated that the experimental equipment at our disposal sufficed to give qualitatively correct results.

As a further precaution, experiments were performed for the purpose of discovering whether the effect of the rotation was also given within the right limits. The Dutch experiments (N.A.C.A. Technical Memorandum No. 307) proved to be very favorable for the production of like operating conditions. Their execution was undertaken by W. Völker. The experimental apparatus was so much improved by increasing its sensitivity, that the results could now be successfully converted into absolute values. The resulting curves showed the same character as the ones obtained from the Dutch experiments. The absolute values of $c_{a\ max.}$ were:

	Holland	Hannover
With gap open and rotor running	1.12	1.09
With gap open and rotor at rest	0.5-0.6	0.33-0.47

Even though the angle of attack was greatly increased (by rotation from about 10° according to the Dutch experiments to about 21°), we thus obtained the most important result, that, as regards the magnitude, the effect of the rotation on the lift is so given by our experimental arrangement that no deceptive distortions occur.

According to the numerous control experiments, Fig. 5 may be accepted as approximately correct. In my opinion, the difference, as compared with previously published articles on airfoil rotors, is due to another fundamental conception. It is known that, for obtaining an undistorted polar curve, the suction side must not be disturbed near the leading edge and, for obtaining high c_a values for small landing speeds, that an increase in the energy of the boundary layer must occur at the spot where it is forced to overcome a higher pressure than is inherent in itself. Dr. G. Lachmann obtained this result with a slotted wing by utilizing the pressure drop between the pressure and suction side (N.A.C.A. Technical Memorandums Nos. 282 and 298). If we realize the magnitude of the effect of the friction on the slot walls, it is obvious that the effect is improved when both slot walls move in the direction of the flow with the velocity of the flow. These considerations served as the basis of the present work. A further incentive came from turbine designing. The attempt was to be made by increasing the peripheral velocity in the slot, to obtain a reaction effect, which would increase the lift and diminish the drag. The shape of the model was determined from a combination of these viewpoints with consideration of the aerodynamic conditions. This shape fulfilled our expectations, according to the experiments under discussion. We would again emphasize the fact that, due to the above-mentioned inadequacies, these experiments are only expected to show in what direction experiments with combinations of airfoils and rotors can give aerodynamically successful results. It should not be assumed that the first design gives the best results.

Although the experiments could not be continued for lack of money, their prospective practical value has been indicated. The method can be utilized only in case it proves more economical than other devices for reducing the landing speed. This is affected chiefly by the weight and reliability of operation. Without going further into details now, I would like to emphasize the fact that surprisingly favorable solutions may be found. The final decision is reserved for the future.

Another objection concerns the peripheral speed and consequently the rotational speed of the rotor. According to Fig. 7, u may equal v. With v = 70 km/h or 19.5 m/s (64 ft./sec.)

and a cylinder radius $r = 0.6$ m (1.97 ft.), n = about 620 and with $r = 0.75$ m (2.46 ft.), n = about 500. It still remains to be tested as to how much the rotational speed can be reduced by making u less than v.

We thus find that the solution of this problem involves very great, though not necessarily insurmountable difficulties.

Translation by Dwight M. Miner,
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for Aeronautics.

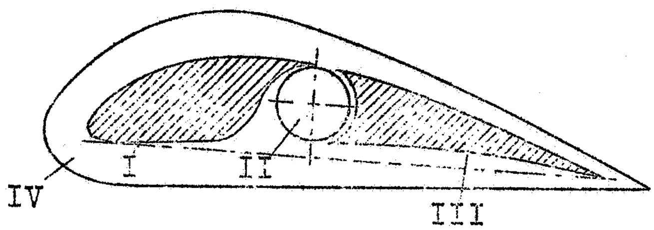
I
II
III
IV

Fig.1

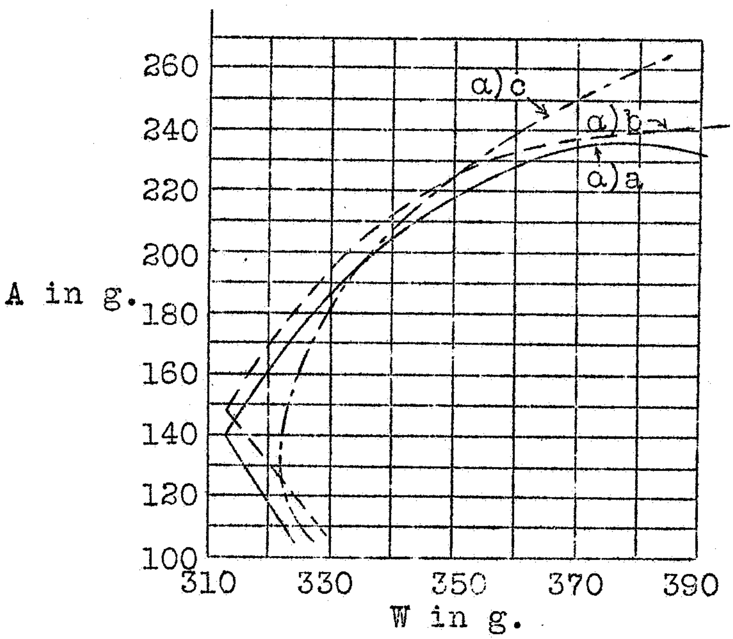
a)c
a)b
a)a
260
240
220
200
180
160
140
120
100
A in g.
310
330
350
370
390
W in g.

Fig.4

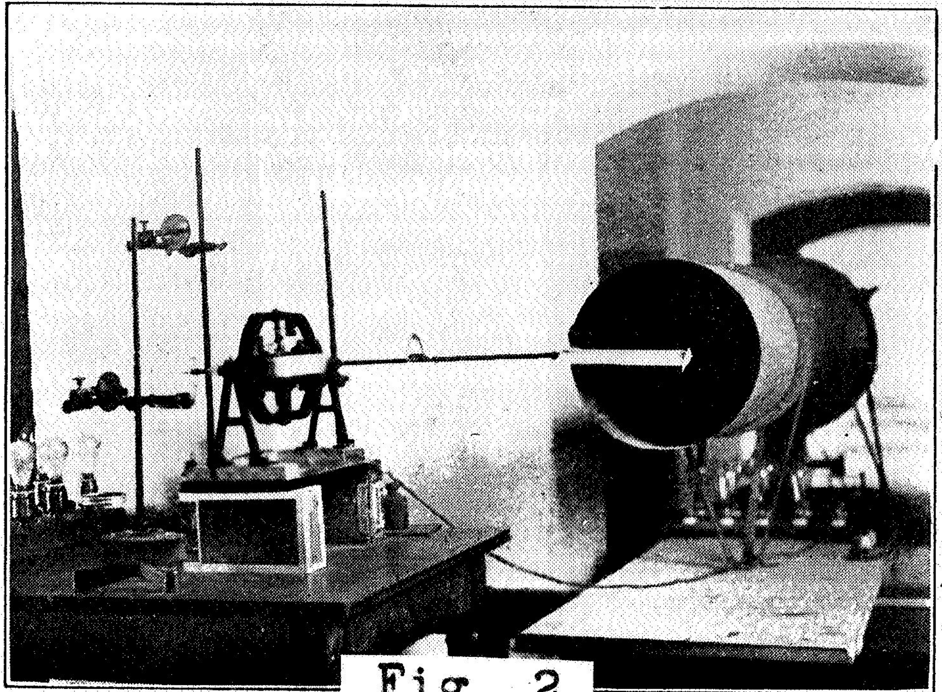

Fig. 2

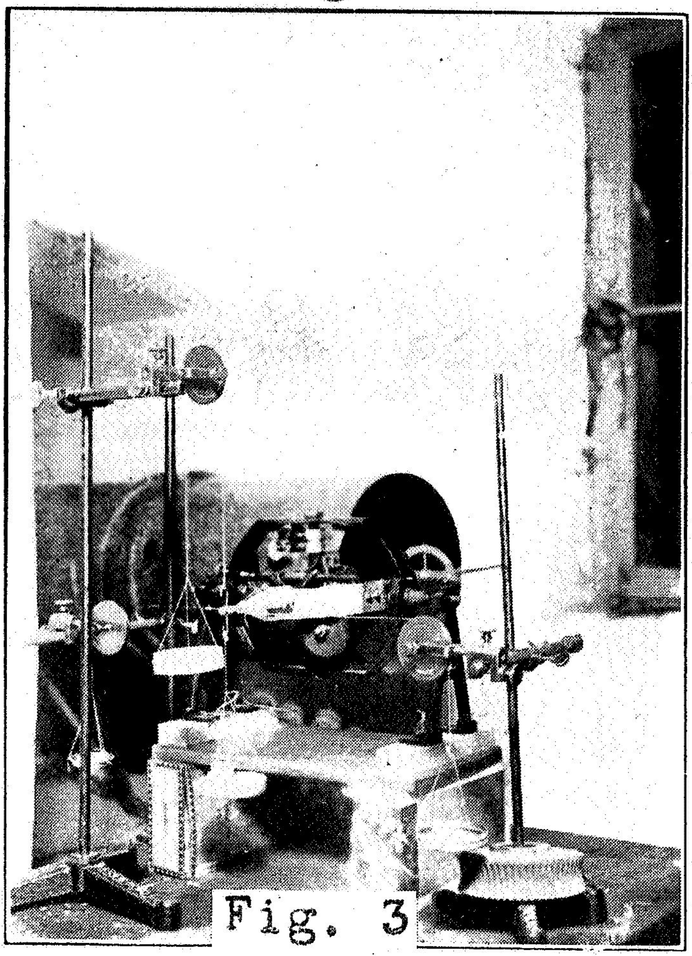

Fig. 3

4065 A.S.

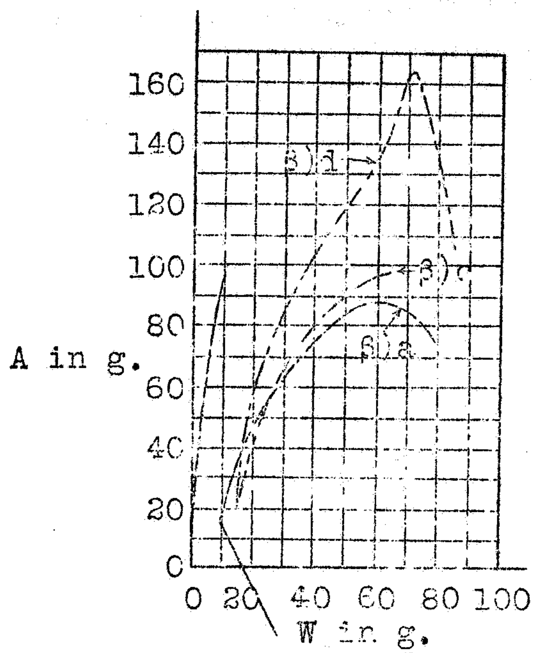

Fig.5

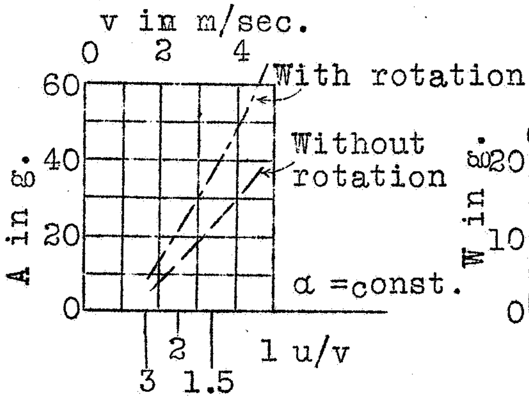

Fig.6

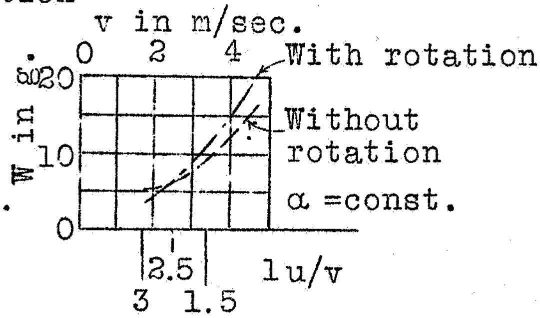

Fig.7